Energy Efficiency and traditional buildings – Historic Scotland's work

As a result of climate change, significant attention is being placed on older buildings as the energy efficiency argument gathers momentum. This attention has been largely driven by the requirements of the Kyoto Protocol drawn up in 1997, which committed nations to reduce carbon emissions across all sectors of activity. This has led to legislation from The European Union (European Performance of Building Directive 2002/91), the UK Government (Climate Change Act 2008) and the Scottish Government (Climate Change (Scotland) Act 2008) to require reduction of carbon emissions. Scotland has set the most demanding reductions, and the built environment, especially housing, has some challenging targets to reach. In all sectors an 80% reduction by 2050, with an intermediate target of a 40% reduction by 2020, is now set in law.

Secondary legislation, in the form of The UK and Scottish Building Regulations, is being developed to progressively raise the standards of energy performance in new build, and with existing structures such regulations are likely to apply when alterations or additions are planned. Existing buildings that do not meet these performance targets are given close scrutiny and are generally referred to as "hard to treat".

How the process of CO_2 emissions reduction is carried out on a wide scale is suggested in a number of policy directions: The Scottish Government is considering ways of ensuring compliance with the targets set in primary legislation. Energy efficiency alone cannot be the only track, although it has been the main consideration in all primary legislation from national governments, where the focus has been to lower operational energy use. Existing historic and traditionally-built structures have a role to play in reducing carbon emissions and for that reason should not play the historic card to avoid doing so.

Traditional buildings are generally regarded as those structures in Scotland built before 1919, with double pitched roofs and solid masonry load-bearing walls built from a limited palette of largely natural materials that were more or less vapour permeable. These structures, comprising an estimated 19% of Scotland's housing stock including tenements, terraces, semi detached houses, detached villas and cottages. Of the pre-1919 stock, tenements are the most numerous, especially in central Scotland, with a high proportion of them in use as social housing where pressure for energy efficiency improvement is high. Such structures are vulnerable to interventions as a result of thermal upgrading, specifically in respect of windows, but increasingly with regard to wall insulation and other changes. How this work is done and to what standard is also an emerging area of concern. The approach taken by Historic Scotland in the area of traditional trades will be the subject of a separate paper – although strongly linked to the development of a low carbon economy.

Historic Scotland has increasingly taken the role of offering advice and guidance for traditionally built structures, over and above those with statutory protection. In consequence the focus of research and publication process has shifted, from detailed research publications on specific subjects to more general guidance for owners of traditionally-built homes and buildings of all types.

The Historic Scotland publication, “Conversion of Traditional Buildings - Application of the Scottish Building Standards” (available from our on-line store) was produced in partnership with the Scottish Building Standards Agency (Building Standards Division) and contained energy efficiency upgrade guidance. Although this guide was an excellent start, more detail was needed, as well as baseline data on the real thermal performance of traditional building elements. This drove a research schedule for building fabric testing where a better baseline performance could be obtained. And with real figures there was a chance to start to develop and articulate stronger arguments for retention of various elements of older structures and give values for use in the various building assessment processes. How older structures are assessed is a developing area although the energy performance certificate (EPC) is possibly the best known to date. Work by Historic Scotland on assessment methodologies has outlined the respective attributes of the different systems such as SAP, RDSAP and NHER and further work is required to in this area.

Thermal Performance of Traditionally built structures

Through a programme of site and lab trials, elements of the traditional fabric have been looked at in terms of thermal performance before and after intervention, to get a feel for what was technically feasible, and what benefits that intervention yielded. Having assessed the performance, it is then possible to address how much it needed to be improved – what is the gap between present and required performance, and how that gap could be narrowed. Historic Scotland is not the only body to conduct research in this field, and some of the work was carried out in conjunction with other projects. In particular, joint working with the Charity Changeworks in Edinburgh was especially fruitful and their subsequent guide “Energy Heritage” on fabric interventions in traditional housing remains probably the most concise and accessible to date.

If appropriate solutions were to be developed for traditional and historic buildings, assistance and guidance were needed to assist industry and the construction sector in developing solutions that are suitable for vapour permeable structures. This guides our approach to building fabric research.

Timber Windows

In Scotland the dominant window type - the vertical sliding sash in a timber case is proven and durable, and was the focus of testing. In a programme run with English Heritage, two windows were tested at Glasgow Caledonian University, in an “as received condition”, and subsequently with a range of interventions. Heat flux metres measured heat transfer through the glazing and allowed an actual U-Value of the interventions to be calculated The interventions ranged from draught stripping, fitting of roller blinds, shutters, and curtains, continuing on to secondary glazing and more invasive options with Double glazed units. The double glazed units were retrofitted into the trial sashes with minor adjustments to the rebates of the sash and astragals. While concerns over long-term durability of such units have been expressed in some sectors, this is more an argument for the manufactures to make the product work, rather than completely prevent its use in principle on the grounds of technical shortcomings. Results are available in the Technical Report "Performance of Traditional Windows".

What the tests showed most strikingly was that the traditional options, especially when used in combination, were very effective and that the double glazed units, while performing well, did not give the best results. It is accepted that curtains and shutters will result in low light levels or darkness, but the lowest external air temperatures are at night. If a room is not occupied, then again, such features not only conserve heat, but reduce damage from ultra violet light damage and excess solar gain. However, several of these options, although effective, are considered "user modifications" in assessment terms and are not counted in any large scale carbon mitigation planning. While use of double glazed units is considered controversial, it has to be better that we have manufacturers making timber windows in an idiom with which we were comfortable, than that industry develop less satisfactory options alone. We are also seeking to build capacity in construction (specifically in joinery manufacture) to allow volume production of timber windows, thus keeping prices low and the products accessible to a wide range of building owners.

In a separate project, in a trial run by Changeworks for the City of Edinburgh Council, and supported by Edinburgh World Heritage Trust, a more detailed study of advanced glazing systems was undertaken. This project evaluated a range of slim profile double glazed units in the windows of a B-Listed property in use as Social Housing. This range of glazing products was trialled for cost, thermal performance, ease of installation and appearance. The windows being tested were modern and all dated from a refurbishment in the 1980s. Historic Scotland funded the testing of the thermal performance and the embodied energy of the products and their installation. The results are encouraging both in terms of thermal performance and appearance, although cost remains an issue. It is hoped that as manufacturing volumes increase the unit costs will come down, and joiners will become more familiar with their use.

Mass walls

The performance of mass masonry walls, common in Scotland, seemed especially unclear, with a lack of measured data and a lot of assumptions (mainly that they perform poorly) among designers and regulatory bodies as to the actual thermal properties of traditional masonry.

A programme of basic research was commissioned that measured a wide range of walls and how they performed thermally, using in situ heat flux metres in a similar manner to the method used for the glazing tests described above. The results gave a generally better performance than expected (calculated U-values for a typical mass wall of 600mm in thickness range from 1.5 to 2.5 W/m^2K) and certain broad conclusions were drawn – namely that a dry mass wall of approx 600mm thickness, very common in Scotland in buildings of all types, generally had a U-value of between 1.0 to 0.9 W/m^2K. The interim report "U-Values of Traditional Walls, interim results" (Technical Paper 2) goes into more detail regarding other walls measured and a further Technical Paper due in January 2011 will describe additional measurements carried out.

In general the type of stone and the build type - ashlar, rubble etc - did not affect the thermal property as such, but the type of lining (lath and plaster, plasterboard or modern plasterboard) made a difference. There were not sufficient results to allow any linear relationship to be made regarding thermal performance and wall thickness, partly because the majority of walls fell within a narrow range of 550 – 600 mm in thickness. The air gap on the inside face, when not excessively ventilated, did provide additional insulation.

Knowing the real U-Value of a mass wall, and accepting that its performance falls short of modern requirements (a U-Value of 0.25 Wm^2K for new build domestic) what insulation options are there - Internal or external insulation? Strip out and re-line or upgrade the linings in situ? From a building and materials conservation point of view, removal of traditional linings such as lath and plaster should not be considered. However, in many cases such finishes may have been removed already, and modern materials may already be in situ – allowing greater intervention. An opportunity arose to test a range of internal insulation products in six Social Housing units in Glasgow dating from C1900. The existing walls were tested for thermal performance before removal of the plasterboard and then the rear walls of the flats were then retrofitted with a range of six different insulation materials.

Some materials were applied directly onto the inside masonry face, while others were fitted on new timber strapping. Following installation the thermal performance of the respective products were tested over a three week period. The insulation materials, ranging from a silica based insulant to a wood fibre board, achieved the designed U-value of 0.33 W/m^2K with minor variation between products.

Insulation Type	**Unimproved U-value W/m^2K**	**Improved U-value W/m^2K**
100mm Hemp board between timber straps	1.1	0.21
90mm Wood Fibre fitted between timber straps	1.1	0.19
30mm insulated	1.1	0.36

board onto timber straps		
50mm Cellulose fibre damp sprayed between timber straps	1.1	0.28
40mm insulated board onto timber straps	1.1	0.22
50mm Bonded Polystyrene Bead	1.1	0.31

The flats were not occupied during the initial post intervention monitoring and therefore (external conditions notwithstanding) the moisture loading was minimal. With sustained occupation over autumn 2010 we will get a better feel for how moisture behaves behind the inside surface. These results are expected in the spring of 2011, when a full assessment of the different insulating materials can be made.

What options do owners have when lath and plaster is in situ? Some early results from U testing on a well-ventilated public building (built as a hospital) were revealing in the role played by the cavity – the better the air flow the greater the u value – and the poorer the thermal performance. So modification (but not closing off) of the air space behind the lath may give us the key to improving performance of such walls. This might take the form of zoning with a loose fill or other material being blown or injected in the void. Considerations of moisture bridging from the outer wall across the cavity reflect misperceptions of the performance of mass walls – the inside face of a mass wall should never be wet, and should always be vapour permeable. With this in mind Historic Scotland will be testing various options for this type of intervention over the winter of 2010, and long-term monitoring will assess the humidity levels at the internal masonry face and how that relates to the humidity of the wall core.

Alternatively, options exist for the application of a thin layer of insulant onto the existing plaster surface – something that might be called "the magic wallpaper". Such products are elusive, although thin vapour permeable insulants for surface application (based on a silica derivative called aerogel) are being developed in Scotland, with a thin enough profile that can make its use over existing internal plaster a possibility. While alone this will not achieve the new standards, in conjunction with a mass wall of reasonable thickness (U- value 1.0 W/m^2K) a value in the region of $0.25W/m^2K$ might be possible. Historic Scotland will also be testing such products over the autumn of 2010.

External insulation is a harder problem to address, as in addition to considerations regarding the architectural aspects – loss of surface and edge details etc - the long-term performance of the layer remains largely unknown. However, many of Scotland's traditional buildings are covered in a layer of modern cement render, with a dry or wet dash finish, lime renders being rare. Given that we know this cement layer is often not performing as the designer intended, and possibly causing dampness and problems in the masonry, its removal and replacement with a vapour permeable insulation layer could be a good thing. However, an insulating render layer sufficiently thin so as not to compromise architectural details has not yet been developed and would only be appropriate where a building, or part of it, was intended to be harled. From a building physics point of view, external insulation that allows full use of the thermal mass – retaining the mass within the insulated envelope - is the best option. High priority therefore should be given to developing a material that can be applied externally in the idiom of a wet cast render, with high vapour permeability, suitable for traditional buildings. Historic Scotland will work with industry and designers to see what might be developed in this market.

Roofs and attics

This aspect of improvement was not tested extensively as it was felt that standards and indicative specification for loft insulation have been developed. However, it was obvious that there was some variation in the application, and that some property types with coombed ceilings (the sloping part of a ceiling on a top floor) in the upper floor were not being as well insulated as they might. Site trials in the winter of 2010/2011 will feature some work to illustrate basic techniques for the fitting and installation of insulation.

Floors

Heat losses through floors are significant in thermal terms, and also in perceived human comfort terms where low radiant temperatures from the heat sink of an un-insulated floor can significantly affect perceptions of warmth. Timber floors at ground level can be insulated by the addition of material underneath the floor although unless there is crawl space it will be necessary to lift the boards. Parquet and hardwood floors are especially problematic, and intervention might not be cost-effective.

Solid floors have more potential. Un-insulated concrete floors are common in Scotland on ground floors in a range of properties, especially traditional buildings that have been modernised before 1990. Such concrete floors can be improved by the addition of a thin insulated floor layer (35mm) on top of the concrete. Tests at Lauriston Place with proprietary insulation gave a six-fold improvement in U-value, a reduction in U-value from $3W/m^2K$ to $0.5\ W/m^2K$. Some trimming of the bottom of doors was required, but skirtings were able to be left *in situ*. The proportions of the rooms were not adversely affected by such a thin layer, and as vapour movement through concrete is minimal, the addition of a further layer was not thought to be damaging. Where original material survives, traditional or historic stone floors can be lifted and re-laid on an insulated lime hemp concrete base layer, or other lime-based material, without a DPC. Relaying a floor in this fashion has been done in a recent conservation project and Historic Scotland will be measuring the U-value and its water vapour handling capacity over the next few months.

Air tightness and air quality

Air tightness is often difficult to achieve in modern buildings, let alone older ones, and while the maxim “built tight, ventilate right” cannot be disputed, the costs of interventions required to achieve a certain standard in most traditional buildings are likely to be costly. Not only do buildings have to be energy efficient, they also have to provide a benign environment for the occupants. Many commentators have raised concerns about ventilation rates in housing of all types and ages, and Historic Scotland funded a scoping study by GAIA Research to look at some of the issues (HS Technical paper 6). Others have commented on the health effects of low air change rates, Stirling Howieson, working at the University of Strathclyde considers why the asthma rates in Scotland are now many times higher than they were in 1960, and suggests that reduced ventilation rates in the United Kingdom housing stock may have been responsible for this trend. From another continent and a different building tradition the Australian author Peter Dingle has highlighted the effects of poor ventilation and “off gassing” from modern construction products and their effects on human health.

There are many well publicised refurbishment cases where Victorian buildings have been extensively reworked with an emphasis on high insulation levels and airtightness. They all perform well in terms of those standards, and the results are good - although achieved by significant interventions and often little remains of the internal fabric – and that degree of removal does beg questions of embodied energy and resource disposal. Ventilation is often provided by extract fans alone, sometimes in intermittent use, with the only other provision for incoming air coming from trickle vents in the new windows. Additional controllable ventilation may be required – possibly utilising existing ventilation features such as chimneys and cupolas. These traditional features of the fabric should be re-configured to allow controllable natural ventilation. Historic Scotland will trial controllable openings in chimney flues to better utilise these inbuilt features in future trials.

Aside from direct air changes and how to achieve them, traditional construction practice can offer a solution in the static idiom as well – traditional finishes such as limewash and distemper offer many benefits in being able to absorb excess water vapour in times of high humidity load. Modern materials such as clay paint and modern distemper can be effective as well, and in addition they have sustainable credentials regarding disposal and chemical make up. Some of these finishes and materials will also be tested by Historic Scotland in a domestic context over the next 18 months and their effects on internal humidity regulation assessed.

Embodied energy and sustainability issues

Physical performance alone is not enough to properly assess existing structures – the benefits in carbon terms must also be argued; and this leads to questions of embodied energy. Failure to appreciate the wider carbon and resource picture can lead to carbon being moved from the domestic energy sector's carbon balance sheet to the manufacturing one. People in modern construction, at every level of the process, from investor to the contractor on the ground, too often regard an existing structure of any age as a block on the site, which is best cleared (Fig. 8). If a planning restriction obliges retention of fabric, sometimes only the masonry survives. Other existing material has no perceived value and so is replaced by modern construction with a modest design life in comparison to what stood before.

It has therefore been necessary to consider the wider impacts of the current imperative to improve energy efficiency (mainly by insulation improvements) over and above the reductions in operational energy use alone. What is the embodied energy expended in refurbishment, and how durable and lasting is the result. How the embodied energy of materials and products is calculated is a complex and emerging discipline, with sometimes wide variation in results depending on the system boundaries being allocated. At present the only standard is ISO 14040 - Life Cycle Assessment.

As part of the Changeworks windows trial, Historic Scotland commissioned research to look at the embodied energy of the original windows, their timber double glazed replacements, and the equivalent window in UPVC. Not surprisingly, the single glazed timber window used comparatively modest amounts of energy, and its double glazed timber replacement likewise used modest quantities as long as only certain types of inert gas were used in the double glazed unit. High performing gas, used in other types of double glazed unit, was high in embodied energy, nearly as high as that of a UPVC window of similar specification. (See Technical Paper 9).

In conservation circles it is often articulated that traditional and historic buildings are "high in embodied energy" and the virtual carbon credits they carry offset their lower thermal performance. The Historic Scotland view is not that they are endowed with points as such, but more that they sit at zero, or are better described as being carbon neutral. The carbon they save is in what does not need to be built in their place. The wider sustainability arguments of new materials, their origin, make up, toxicity and disposal costs are being increasingly considered during procurement and were well articulated in a recent RICS report, "Redefining Zero" and are likely to be part of a sustainability assessment process in future planning.

Developing this work on materials, Historic Scotland has commissioned a study on the embodied energy of imported stone compared to stone extracted in Scotland (Technical Paper 7) The findings clearly articulate that in carbon terms imported stone from China, India or South America produce up to 10 times the carbon dioxide equivalent of stone procured locally. This type of procurement also contributes to a range of environmental metrics such as regional resilience, sustainable communities and shorter travel footprints as well as economic diversity and sustainable growth. Issues around a regional supply chain of traditional materials and embodied energy considerations were presented and discussed at the Historic Scotland "Energy Efficiency and Sustainability in Traditional Buildings Conference" in March 2010. Presentations and material from this and a previous conference are available online at www.historic-scotland.gov.uk/energyefficiencyintraditionalbuildings.htm

Passive design

In terms of passive performance, traditional buildings are often able to perform well - when the building fabric is allowed to function as intended. This may be through natural ventilation and thermal mass or at a more detailed level the performance of the hydroscopic materials mentioned above. Sometime these properties are best illustrated in buildings designed and configured for public use, where the ventilation requirement was highest. In these cases natural ventilation was a key part of the design, and even a part of the architectural idiom. The flèches of medieval illustration and many Victorian town halls are not gothic folly – they are a functioning part of the structure, for the benefit of the users and the fabric. Schools, village halls, courts and libraries also rely on this principle. Practice in refurbishment in recent years has often specifically instructed the sealing of vents of all forms, replaced by a mechanised air handling system.

This practice of blocking off passive systems and retrofitting mechanical systems has a fairly recent, but extensive, pedigree, examples include: Albert Hall, London; Tate Gallery, London; Dean Gallery, Edinburgh and City Chambers, Glasgow . In each case non-mechanical systems were replaced by HVAC systems, seeking to run within tight tolerances but at a high financial (and carbon) cost, resulting from cooling loads or climate management. The cost in carbon terms to cool is more than to heat; this is due to different fuel sources: cooling is electrically powered and more carbon intensive than heating, which is largely powered by gas. The rise of domestic air conditioning is a considerable concern as it has the potential to negate all the carbon savings generated through energy efficiency measures. [21] buildings that overheat tend to be non domestic and modern – heavily serviced with considerable plant. The study of the energy consumption of English Court Service buildings supports this by demonstrating that pre-1945 structures consumed less energy than their more modern counterparts, with the lowest energy users being the Victorian stock, possibly largely due to the lack of cooling load.

The requirement for extensive air handling systems is being questioned however, and the recent Carbon Trust's guidance for the non-domestic sector "Building for the Future" released earlier this year specifically draws attention to the benefits of passive cooling (and the energy used in air conditioning). Aside from running costs, plant and equipment can only be kept running if spares can be obtained. As product lifecycles shorten, a lot of plant can become obsolete after only 10 years. Passive design and function are low carbon principles that older structures relied on. Low carbon buildings should not be packed with gadgets and kit, because if they are sufficiently well designed and configured they should not need it. Traditional buildings demonstrate this amply, and Historic Scotland will seek to demonstrate these principles through practical site trials in 2010-2011.

Future work

Historic Scotland, a part of Scottish Government, is actively involved with other Government Departments to develop a range of improvement options for the range indigenous housing stock, especially in the field of Social Housing. Historic Scotland will take forward work on energy efficiency in the non domestic and domestic sector through a second phase of site interventions and evaluation part funded through the Scottish Governments Energy Efficiency Action Plan.

Trials will be conducted in a range of traditionally built properties to further develop simple and cost-effective interventions that are replicable across the housing and other built stock in Scotland. Key to this will be work with Residential Social Landlords, who operate and maintain a significant proportion of Scotland's housing stock. Trials are being conducted on tenement flats, detached cottages, a former primary school conversion, a working primary school and a large office building. These projects, carried out mostly on unlisted structures, will be published as case studies and will seek to guide best practice in the refurbishment sector. These projects and other work are tabulated as part of the Historic Scotland Conservation Group Research Strategy which can be viewed at www.historic-scotland.gov.uk/conservation-research In addition to site trials, dialogue is being developed with a range of stakeholders involved in the delivery of training and the provision of advice to the business and residential sector. Technical solutions will only be effective if there are the professional skills to properly specify and direct the work, and the trade skills to carry out this work to a proper standard.